Capturing Motion and Depth before Cinematography

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ABSTRACT

Visual representations of biological states have traditionally faced two problems: they lacked motion and depth. Attempts were made to supply these wants over many centuries, but the major advances were made in the early nineteenth century. Motion was synthesized by sequences of slightly different images presented in rapid succession and depth was added by presenting slightly different images to each eye. Apparent motion and depth were combined some years later, but they tended to be applied separately. The major figures in this early period were Wheatstone, Plateau, Horner, Duboscq, Claudet and Purkinje. Others later in the century, like Marey and Muybridge, were stimulated to extend the uses to which apparent motion and photography could be applied to examining body movements. These developments occurred before the birth of cinematography, and significant insights were derived from attempts to combine motion and depth.

Keywords stroboscopic motion, stereoscopic vision, optical instruments, pre-cinema

> I have given this instrument the name of *Dædaleum*, as imitating the practice that the celebrated artist of antiquity was fabled to have invented, of creating figures of men and animals endued with motion. (Horner, 1834a, p. 37)

Introduction

Space and time are basic aspects of perceiving our environment: objects occupy volumetric space and either they move or the observer viewing them moves. Visual representations have traditionally been devoid of the third dimension of space and the passage of time: pictures represent objects in two dimensions and their motions are absent or implied. Fundamental advances in the perception of space and time were made in the second quarter of the nineteenth century. Instruments for the synthesis of motion and depth were invented and applied to the visual representation of animal and human motion. Studies of visual persistence led to the invention of the first instruments to synthesise visual motion from still images and the stereoscope synthesized depth perception from two flat images.

The words at the head of this article were written by William George Horner (1786-1837) whose instrument enabled motion to be seen by presenting a sequence of slightly different images in rapid succession. Horner did not claim to have discovered the phenomenon but the virtues of the dædaleum were that apparent motion could be observed by several people at the same time and that it did not need a mirror. Apparent motion had been described over a year earlier by Joseph Antoine Ferdinand Plateau (1801-1883) and by Simon Stampfer (1792-1864). Both Plateau, with his phenakistiscope or fantascope, and Stampfer, with his stroboscopic disc, developed similar instruments for presenting a series of still pictures in rapid succession (see Fig. 1). Stampfer's stroboscopic disc was very similar to Plateau's phenakistiscope or fantascope, and both acknowledged the stimulus provided by Faraday's (1831) article on optical deceptions. Plateau (1833) described the instrument as: "a cardboard disc pierced along its circumference with a certain number of small openings and carrying painted figures on one of its sides. When the disc is rotated about its centre facing a mirror, and looking with one eye opposite the openings... the figures are animated and execute movements" (p. 305). Stampfer (1833) described his stroboscopic disc in similar terms to Plateau: "The principle on which this device is based is that any act of vision which creates a conception of the image seen is divided into a suitable number of single moments; these present themselves to the eye in rapid succession, so that the ray of light falling on the change of the images is interrupted, and the eye receives only a momentary visual impression of each separate image when it is in the proper position." (translated in Eder, 1945, pp. 499-500). The instruments were commercialised soon after their invention. The London instrument maker, Ackermann, produced phenakistiscopes for sale in 1833, and Trentsensky and Vieweg were selling stroboscopic discs in Vienna in the same year. There followed a veritable craze for spinning discs, which were sold widely throughout Europe.

Figure 1 about here

A similar fate did not befall Horner's dædaleum. He did not include an illustration of it in his article: it consisted of a cylinder mounted on a vertical axis, with slits at regular intervals, and a sequence of drawings on the opposite inside surface of the cylinder (Fig. 2). Unlike Plateau and Stampfer, relatively little is known about Horner.

He was born in Bristol, where his father (a Methodist minister) taught at Kingswood School which was founded by John Wesley. William became a teacher and head teacher at the school and then founded another (the Classical Seminary) in Bath in 1809. His mathematical work was widely acknowledged after publication of his method for solving numerical equations which became known as 'Horner's method' (Horner, 1819). It is not clear what stimulated his interests in optics and vision but these were evident from an early article on the camera lucida (Horner, 1815) and a text on *Natural Magic* (Horner, 1832) in which he took issue with some of Brewster's (1831) interpretations of mirror reflections. He made two substantial contributions to vision research. The first was the dædaleum, which he described as follows:

> The apparatus is merely a hollow cylinder, or a moderately high margin, with apertures at equal distances, and placed cylindrically round the edge of a revolving disk. Any drawings which are made on the interior surface in the intervals of the apertures will be visible through the opposite apertures, and if executed on the same principle of graduated action, will produce the same surprising play of relative motions as the common magic disk does when spun before a mirror. But as no necessity exists in this case for bringing the eye near the apparatus, but rather the contrary, and the machine when revolving has all the effect of transparency, the phænomenon may be displayed with full effect to a numerous audience. (Horner, 1834a, p. 37)

Figure 2 about here

Despite the advantages the dædaleum had over rotating discs, it was not exploited as they were. The instrument was given new life (and a new name) in the 1860s as the zoetrope (see Herbert, 2000; Mannoni, 2000; Wade, 2004). Thus, the 'wheel of Daedalus' became the 'wheel of life'! William Benjamin Carpenter (1868a, b) discussed the newly named zoetrope and its effects in two articles which examined its antecedents. Remarkably, while lauding the stimulus provided by Faraday for development of phenakistiscopes and stroboscopic discs, no mention was made of Horner and his dædaleum. The zoetropes patented in the late 1860s were essentially the same as Horner's instrument and many of the image sequences made for them involved human or animal movements. Moreover, the period between the dædaleum and the zoetrope witnessed the birth of photography so that sequences of photographs could be "endued with motion".

Apparent motion was not the only aspect of vision examined by Horner. In the same year he published an article which provided the clearest representation of the retinal blood vessels published to that date (Fig. 2). He described the appearance thus:

> In all experiments upon one eye, the comfort of the other contributes materially to success. A case should be bound over it, so as completely to darken it, without touching the eyelids. It has, by all observers, been experienced, that a distinct view is not to be maintained, unless the light is kept in motion. The lens or the cardboard must be moved slowly backwards and forwards edgewise, so that the light may traverse the interval between the cornea and the angle or lid of the eye. The drawing (fig. 1) exhibits, with as much accuracy as my slender graphic skill

admits, the result of numerous and varied observations of the vessels of my *right eye*. The cross (+) indicates the *centre* of the field of view, or the point of direct vision. Beneath O is the *origin* of the larger vessels.... To exhibit the more minute vessels, which either from my perception improving from habit, or possibly from continued excitement, appeared much more numerous in my later than my earlier trials, fig. 2 is an enlarged figure of the more central vessels, and of the peculiar appearance of the central portion of the ground of the picture. At the centre (+) of the ground of the picture, which "corresponds to the projection of the *foramen centrale*," C.W. observed a crescent-like appearance, indicating in his opinion "a slight convexity or concavity in the retina at that point." In my own eye, whether the right or the left, no trace of such a crescent is found, but the appearance of a granulated texture in the level surface, like a number of exceedingly minute polished spherules collected within an obscurely defined circular space, as represented in fig. 2. (Horner, 1834b, pp. 263-264)

The C.W. referred to was Charles Wheatstone (1802-1875). In 1830 he provided a précised translation of Purkinje's (1823) book on subjective visual phenomena, one of which was the visibility of the retinal blood vessels. Wheatstone (1830) described a better way of rendering them visible and it is this technique that was applied by Horner. Wheatstone played a pivotal role in linking retinal disparity to stereoscopic depth perception as well as indicating how it could be combined with apparent motion (Wade 2012). He was in stimulating company as many other scientific worthies in London were involved in studies of vision (Fig. 3).

Figure 3 about here

Young (1800) was the initial catalyst, describing how the paths of vibrating piano strings could be seen with the aid of a magnifying lens. His ideas were implemented by Wheatstone (1827) with his kaleidophone, which rendered the oscillations of rods visible to the naked eye. It was so called after the beautiful patterns that could be seen with Brewster's (1818) kaleidoscope. Wheatstone made his stereoscope in the next decade. Roget (1825) analysed the curved patterns seen when spoked wheels passed behind vertical railings and claimed to have made an instrument to simulate motion. Paris (1827) made the thaumatrope or wonder-turner which combined patterns printed on opposite sides of a spinning disc. Faraday (1831) constructed a pair of counter-rotating sectored-discs to display the shadows they produced during motion. The instruments they invented are listed in Table 1, together with others that are related to cinematography and neuroscience. They were called 'philosophical toys' because they combined science with entertainment. They fulfilled the dual role of instruments for scientific experiment and devices for extending awareness of the senses (Wade, 2004). Stereoscopic depth will be treated first before examining motion and its combination with stereoscopic depth perception.

Table 1 about here

Capturing motion

Persisting images had been known about since antiquity and a variety of instruments were made to exploit the continuous visibility of moving objects (see Wade, 2004). The breakthrough came when a sequence of still pictures was made to appear in motion. Roget (1825) provided the impetus for examining visual persistence with moving bodies following an analysis of the appearance of spoked wheels rotating behind or in front of vertical railings. The initial description appeared in a brief note over the initials J.M.: "When a spoked wheel, such as that of a carriage, or the fly of an engine, is viewed in motion, through a series of vertical bars, spokes assume the peculiar curvatures which are represented" (1821, pp. 282-283). Roget, better known for his *Thesaurus* than for his experiments on vision (see Wade, 2011a, b), was fascinated by this phenomenon. He provided illustrations and a mathematical analysis, relating it to persisting visual images. In the conclusion to his article he observed that it "might therefore, if accurately estimated, furnish new modes of measuring the duration of the impressions of light on the retina" (p. 140). Later, Roget (1834) suggested in his *Bridgewater Treatise* that he had made a device like the phenakistiscope even earlier than Plateau: "I constructed several of these at that period (in the spring of 1831), which I showed to my friends; but in consequence of occupations and cares of a more serious kind, I did not publish any account of this invention, which was reproduced on the continent in the year 1833" (p. 416).

Faraday (1831) suggested that: "The eye has the power, as is well known, of retaining visual impressions for a sensible period of time; and in this way, recurring actions, made sufficiently near to each other, are perceptibly connected, and made to appear as a continuous impression" (p. 210). This statement excited the interests of others to construct instruments that could synthesize motion from a sequence of discrete images. In 1833, both Plateau and Stampfer developed similar instruments for presenting a series of still pictures in rapid succession (see Fig. 1). Stampfer's stroboscopic disc was very similar to Plateau's phenakistiscope, and both acknowledge the stimulus provided by Faraday's article. There was an understanding of the critical disc velocities required in order to create an impression of visual motion. Plateau (1833) appreciated that if the rotation was too slow then each individual figure was seen; if it was too fast then they were all seen together in a blur.

Capturing motion photographically

In the late 1830s, when the lens-camera was wedded to light sensitive metal plates by Louis Jaques Mandé Daguerre (1789-1851) or to chemically coated paper by William Henry Fox Talbot (1800-1877), its influence on visual representation was immense (Newhall, 1986; Weaver, 1986). Although cameras with lenses had long been known, fixing images formed within them was a novelty. This period was also noted for the invention of a variety of instruments that could assist both artists and scientists. The photographic camera enabled artists to capture scenes in perspective with comparative ease, whereas scientists could consider the eye as a similar optical instrument. They also assisted scientists in producing pictures that could be displayed in the newly invented philosophical toys.

Stroboscopic discs presented stimuli discretely, briefly, and in succession; that is, a sequence of drawings differing slightly from one another were viewed successively through slits in a rotating disc. To the astonishment of observers a single figure appeared in motion: perceived movement was synthesized from a sequence of still pictures. Jan Evangelista Purkinje or Purkyně (1787-1869) made a variant of the stroboscopic disc in 1840 which he called it the phorolyt or kinesiskop (Fig. 4); it was sold commercially as a magic disc (Matousek, 1961). Purkinje used his phorolyt to produce dynamic images of a range of natural movements generated from a sequence of static drawings and photographs. These varied from the pumping action of the heart to the walking movements of newts. He also used it to display photographs of his own rotating posture (Fig. 4), which was particularly appropriate because he had investigated the effects of body rotation on balance and visual vertigo (Wade and Brožek, 2001). In addition, Purkinje utilised photography to represent a wide range of facial expressions, and he was himself the actor (see Wade, 2013).

Figure 4 about here

Purkinje was well aware of the advantages that sequences of photographs 'endued with motion' could provide for science: "… in the field of physiology, the motion of the heart, the blood circulation, the nerve currents, the muscle activity; in natural history, the movement of various animals on the ground and in the air, the most diverse play of colors, physiognomic expressions on the human face, dramatic motions, the growth of plants and other organic bodies, figurative representation from all sides, which otherwise is not possible to execute on a simple plane" (Purkyně, 1865, translated in http://monoskop.org/Jan_Evangelista_Purkyn%C4%9B#CITEREFHubatov.C3.A1-Vackov.C3.A12005).

Purkinje's idea of combining sequences of photographs was to bear fruit later in the century, when Eadweard Muybridge (1830-1904) and Étienne-Jules Marey (1830-1904) studied the dynamics of biological motion with the aid of sequenced photographs. Both

Muybridge and Marey used phenakistiscopes and zoetropes in their investigations but sequences of photographs could also be presented with the praxinoscope, devised by Charles-Émile Reynaud in 1877. It was a modification of the dædaleum/zoetrope which involved mirror reflections. A series of twelve prismatic mirrors were arranged around a central cylinder; they reflected the images placed opposite to them within the outermost part of the cylinder and illuminated from above. Rotation of the cylinder about a vertical axis resulted in the images being reflected in sequence. The main advantage of the praxinoscope over the dædaleum/zoetrope was that the images were brighter both because of the illumination from above and the absence of dark periods between successive exposures. Moreover, in 1880 Reynaud suggested that the effects would appear more compelling if photographs rather than drawings were presented in sequence and that by reflecting the images outside the confines of the cylinder the praxinoscope offered the possibility of projecting the sequence so that it could be seen by many spectators. Reynaud extended the praxinoscope so that it was marketed with a viewing box and mask through which the images could be seen (Fig. 5); this was called the praxinoscope theatre and it was followed by the théatre optique (see Mannoni, 2000).

Figure 5 about here

In 1879 Muybridge modified Plateau's phenakistiscope to view the sequences of photographic images mounted around the circumference of a disc, so that they could be projected via a magic lantern onto a screen; he called it a zoöpraxiscope (Fig. 6). Having photographed actions (mostly of horses and humans) with a battery of up to 24 cameras, the images were hand drawn from the photographs onto transparent glass (see Brookman, 2010). Muybridge's theatrical performances of bodily movements were delivered around the world to audiences eager to see simulated motion of realistic subjects. Muybridge published his eleven volume *Animal Locomotion* in 1887; it consisted of plates with sequences of photographs of humans and animals in motion; volume 8 was concerned with abnormal movements of males and females.

Figure 6 about here

Marey adopted a more scientific approach to capturing motion (Marey, 1873, 1879, 1895; see Braun, 1994). He wrote "Motion is the most apparent of the characteristics of life; it manifests itself in all the functions; it is even the essence of several of them… The most striking manifestation of movement in the different species of animals is assuredly locomotion" (1879, pp. 27 and 102). His interests were in the physiology of biological motion and his desire was to provide quantitative techniques for investigating it. To this end he sought to reduce dynamic actions to their static components. Initially Marey applied his graphical method which recorded activity and motion with the aid of ingenious devices he invented. The use of instantaneous photography was in the air when Marey's *La machine animale* was published (1873): some of his scientific acquaintances were discussing the possibility of studying bird flight in this way (Mannoni, 2000). Marey developed two photographic methods to record animal motion. One involved recording activity on a single photographic plate and the other recorded separate images of the action; they were called chronophotographs (Fig. 7). His description of the process was: "Since the object of chronophotography is to determine with exactitude the characteristics of a movement, such a method ought to represent the different positions in space occupied by a moving object, *i.e.* its trajectory, as well as define the various positions of this body on the trajectory at any particular moment" (1895, p. 54).

Both methods consisted of shuttering mechanisms on the camera; the first produced multiple exposures, and a photographic rifle was invented for the second. A rotating disc exposed different images in rapid succession. Twelve images could be taken in 1 second so that complex actions, like the flight of a bird, could be fractionated in time. A great advantage of the photographic rifle over Muybridge's method was that the action to be recorded was not confined to an arbitrary location; even the flight of birds could be filmed, and this was the subject of Marey's first forays with his rifle, in 1882. He even made models of birds in flight so that they could be viewed in a large dædaleum/zoetrope (Fig. 7) in order to simulate their movements. The shortcomings of paper negatives for recording such short intervals were overcome by using celluloid film.

Figure 7 about here

It was around this time that medical photography came to the fore. Charcot was instrumental in forming a photographic department at La Salpêtrière in 1878, and Albert Londe (1858-1917) developed chronophotography to capture images of neurological patients (see Aubert, 2002). Both Muybridge and Marey took photographic sequences of the gait of neurological patients.

Capturing depth

Wheatstone (Fig. 8) was to have the greatest impact on the development of apparent motion and depth. The stereoscope, perhaps more than any other instrument, ushered in the era of experimentation to vision. It is a simple optical device that presents slightly different figures to each eye; if these figures have appropriate horizontal disparities then depth is seen. The stereoscope transformed not only our picture of vision, providing an instrument to bolster inferential theories of vision, but also the vision of pictures. Paired photographic images of distant scenes could be seen in depth, and this intrigued a public eager for enhancement of the senses.

Figure 8 about here

Prior to the invention of the stereoscope, theories of binocular vision were based on either the combination of corresponding points to yield singleness, or the suppression of signals from one eye (see Wade and Ono, 2012). Experiments on binocular vision had been conducted prior to Wheatstone's investigations, but the link between disparity and depth had not been forged. He himself did not need any optical assistance because he was able to free-fuse stereo-pairs with ease. That is, he could under- or over-converge his eyes so that neighbouring images could be seen in the same visual direction. He also used the then long-known method of viewing figures down two viewing tubes. However, many of his acquaintances found difficulties with these techniques, and so Wheatstone made the stereoscope (see Fig. 8). In the early 1830s the London instrument makers Murray and Heath constructed both mirror and prism stereoscopes for him; only the mirror model was described in his first publication on binocular vision (Wheatstone, 1838). With the aid of the stereoscope and suitably drawn stereo-pairs, Wheatstone was able to demonstrate that apparent depth could be synthesized. The sign of the depth, whether nearer or farther than the fixation point, was dependent upon the direction of disparity; reversing the disparity reversed the direction of depth seen. There were limits to the extent of disparity that yielded depth perception, and radically different figures, like letters of the alphabet, when placed appropriately in the stereoscope engaged in binocular rivalry (see Wade and Ngo, 2013).

Wheatstone analysed the factors that normally accompany an approaching object: increases in retinal image size, retinal disparity, convergence, and accommodation. In his second contribution, Wheatstone (1852) examined each of these factors in isolation, after the manner of experiments in physics. He modified the mirror stereoscope to have adjustable arms, so that changes in convergence could be studied without changes in retinal disparity; he had a variety of stereo-photographs taken of the same object with variations in disparity; he viewed the images through artificial pupils to control accommodation; retinal magnitude was increased without change in retinal disparity. The factors of greatest importance were retinal disparity and convergence.

The most popular model of stereoscope was Brewster's (1849) lenticular version (Fig. 9), although he illustrated a wide variety of methods for combining stereo-pairs (Brewster, 1851), as did Dove (1851). The optical manipulation of disparities was also achieved with Wheatstone's (1852) pseudoscope, which reversed them, and with Helmholtz's (1857) telestereoscope, which exaggerated them. The anaglyph method, enabling overprinted red and blue images to be combined through similarly coloured filters was introduced at about the same time by Rollmann (1853).

Figure 9 about here

Brewster's first stereoscope was made by George Lowdon (Fig. 9), an optical instrument maker in Dundee. He had earlier made acquaintance with Brewster:

> who had at this period (1849) invented his stereoscope, and I got the making of the first one, and the sending of copies of it to many scientific men all over Europe. Later on I also improved on them, and made a great number for many years afterwards. The fault of Brewster's stereoscope was that the lenses were too small, being, in fact, only the two halves of a spectacle glass. This did not suit every eye, and in experimenting I discovered that larger lenses were an advantage. I pointed this out to Sir David, but he was wedded to his own opinion, and as I feared that the idea might be taken up by another, I took out a patent for my improvement – which experience has since amply justified – but my action was, unfortunately, resented by Sir David, and gave rise to considerable friction, for which I did not consider I was to blame, seeing I had pointed out the improvement, and he had refused it. (Lowdon, 1906, pp. 7-8)

This disagreement led Brewster to seek another optical instrument maker to produce it. None in Britain would accept the proposal because of Brewster's reputation. In 1850 he travelled to Paris where Abbé François Moigno (1804-1884) introduced him to the optical instrument maker Louis Jules Duboscq (1817-1886), who made the stereoscopes thereafter.

One of Duboscq's models was presented to Queen Victoria at the Great Exhibition of 1851. Brewster's description of Duboscq's "beautiful stereoscope" carries the latter's portrait in Fig. 11. Duboscq made many stereoscopes which sold widely throughout Europe. However, he was less than honest in his commercial dealings as he claimed to have invented the stereoscope and filed a patent to that effect in 1852; it was not revoked until 1857 (Mannoni, 2000). Despite Duboscq's dubious patent, his optical workshop in Paris added many innovations to stereoscopy.

Capturing depth photographically

In the year after publication of Wheatstone's first article on the stereoscope, his friend, Talbot, made public his negative-positive photographic process. Wheatstone immediately grasped the significance of photographing scenes from two positions, so that they would be seen in depth when mounted in the stereoscope. In 1840, he enlisted Talbot's assistance to take stereo-photographs for him; when they were sent, the angular separation of the camera positions used to capture the two views was too large (47.5 deg) and Wheatstone suggested that 25 deg would be more appropriate. Klooswijk (1991) has reprinted a section of Wheatstone's letter to Talbot, and has himself taken stereo-photographs of the bust Talbot probably employed from camera angles of 47.5, 25, and 1.75 deg. Wheatstone showed how the photographic camera, in combination with the stereoscope, could be employed to reintroduce the dimension of depth to the perception of pictures. However, a single camera was employed to take two photographs from slightly different lateral separations. Brewster made a binocular camera so that stereoscopic photographs could be taken simultaneously.

Brewster announced his binocular camera for taking stereoscopic photographs at the same meeting of the British Association for the Advancement of Science (1849) as the description of his lenticular stereoscope; a fuller account was presented two years later and in his book on the stereoscope (Brewster, 1851, 1856). The camera, shown in Fig. 9, had the lenses at a fixed separation. Added to the many dimensions of disagreement between Brewster and Wheatstone was that of the camera separations required for stereophotographs. Brewster argued that the lens separations should always correspond to those of the eyes, despite the fact that the paired images of distant objects would be virtually identical. Wheatstone (1852) was much more pragmatic and provided a table of camera separations for objects at different distances. Thus the union of the stereoscope and photography was forged, and both Wheatstone and Brewster were captured in stereo (Fig. 10). Wheatstone's stereodaguerreotype was taken by Antoine François Jean Claudet (1797-1867) and Wheatstone was a catalyst in encouraging both Claudet and Duboscq to combine stereo and motion.

Figure 10 about here

Duboscq patented several models of stereoscope, and his optical workshop added many other innovations to stereoscopy (Mannoni, 2000). Claudet was born in Lyon and moved to London in 1829. He was a student and then partner of Daguerre and improved the daguerreotype process. He opened the first daguerreotype studio in London and became recognised as a scientist as well as a photographer (Gill, 1967). He advocated Wheatstone's procedures for taking stereoscopic photographs of objects: "the binocular angle of stereoscopic pictures must be in proportion to the ultimate size of the pictures on the retinas, larger than the natural angle when the images are magnified, and smaller when they are diminished" (Claudet, 1860, p. 22). He had earlier made an instrument called a stereoscopometer which calculated the angle required to take stereoscopic photographs of objects or groups. Duboscq and Claudet are shown in Fig. 11.

Figure 11 about here

Capturing motion in depth

Wheatstone had seen the advantages that photographic images could provide for stereoscopy, and his ideas were widely followed. Many saw stereoscopic photographs as the only form that would be used, and many of the major nineteenth century photographers, like Matthew Brady and Muybridge, produced remarkable stereo photographs. The possibility of combining stereo with apparent motion was also suggested by Wheatstone in a letter to Plateau in 1849. Plateau passed on the suggestion to Duboscq:

> One could go still further, taking advantage of an idea communicated to me by M. Wheatstone, which consists of combining the principle of the Stereoscope with that of the Phenakistiscope… Thus figures simply drawn on paper will be seen indisputably in relief and moving, and in this way will present, in a complete manner, all the appearances of life. This will be the illusion of art brought to its

> highest degree… M. Wheatstone has conceived obtaining, by means of photography on paper, two pictures of an object by placing the daguerreotype in two different positions, such that the two images have the necessary relationship between themselves. (Mannoni, 200, p. 338)

Duboscq called his instrument for combining apparent motion with stereoscopic depth a bioscope (see Wade, 2012). The fact that it did not catch the public mood, like the stereoscope and phenakistiscope had done, suggests that these early combinations of stereo with apparent motion were less than successful. This is evident from the comments and experiments of Claudet. He also combined stereo and motion in a shuttering device that was rather like Duboscq's (Gosser, 1977). A report in *La Lumière* of May 1852, stated:

> M. Claudet informs us that he has constructed a stereoscope in which one can see a person moving, for example a lady working with a needle and making all the necessary movements, a smoker with his cigar moving in and out of his mouth while exhaling smoke, people who drink and toast one another in the English way, steam engines in motion, etc. M. Wheatstone, on his side, without knowing about the device proposed by M. Claudet, seeks to resolve the same problem, and in a few days the mechanisms proposed by the two physicists will be published. M. Wheatstone and the inventor of the phenakisticope (Plateau) have been struck for several years by the possibility of applying stereoscopic principles to the

effects of the phenakisticope, but at present have not been successful. (Anon 1852, p. 88)

Claudet took out a patent for his instrument in 1853, but Wheatstone appears to have abandoned his attempts and did not return to them for over a decade. However, Claudet was not convinced that depth was seen although motion certainly was. He did not present the stereoscopic pairs simultaneously, as Duboscq did, but presented them in rapid succession. When looking back at his early efforts, Claudet (1865a) noted that he had “constructed his instrument in such a manner that by means of a slide with one hole he can, by moving it rapidly in a reciprocating horizontal direction, shut one lens while the other remains open; and in continuing that motion, while one eye sees one of the two pictures, the second eye cannot see the other picture” (pp. 9-10). Since the motion was controlled by hand and therefore the timings will have been variable and this could have been the reason why motion was more easily seen than stereo. Claudet’s method is a precursor of the electronic shuttering systems that have been employed more recently (Blundell, 2011). He did not produce the instrument commercially, and described his endeavours at a meeting of the British Association, and more fully in *The British Journal of Photography* (Claudet, 1865a, b). He commented favourably but cautiously on Duboscq’s system: “M. Duboscq made some ingenious attempts in this direction, but not entirely satisfactory” (1865a, p. 9). Claudet seems to have been a more astute observer than Duboscq as well as a more honest inventor. For example, he noted that with his alternating vision technique "Another curious phenomenon of this alternative vision is, that one cannot distinguish by which eye the object is seen by" (1865, p. 10). Many novelties were added to the instruments for combining depth and motion in the following decades (see Gosser, 1977; Herbert, 2000; Mannoni, 2000; Zone, 2007), but Duboscq and Claudet were the pioneers. They might not have been successful but they did whet the appetites of both scientists and the public for seeing synthesised motion stereoscopically.

Both Muybridge and Marey were stimulated to combine stereo with motion. Indeed, most of Muybridge's early photographs were stereoscopic and one of his first forays into motion used stereoscopic photographs and two zoetropes. In his *Animal Locomotion* Muybridge described it thus: "The respective halves of the stereographs were made simultaneously visible by means of mirrors – arranged on the principle of Wheatstone's reflecting stereoscope – successively and intermittently, through the perforations in the cylinders of the instruments, with the result of a very satisfactory reproduction of an apparently miniature horse trotting, and another galloping" (Brookman, 2010, p. 88). However, as noted above, he did not persevere with stereo motion as most of his subsequent work was with his zoöpraxiscope. Rather than taking stereoscopic photographs of human movements he generally photographed them from different vantage points. Marey (1895) described stereoscopic photographs of the trajectory followed by a light mounted on a moving man and also touched upon taking stereoscopic images with his photographic rifle, but he did not dwell on these innovations. Motion and depth operate in harmony for naturalistic viewing but it is more difficult to bind their simulations harmoniously.

Conclusion

Throughout this tangled history, one figure has woven the disparate threads together – Charles Wheatstone. He devised the kaleidophone for demonstrating persisting images, he invented the stereoscope, he gave directions for the first stereoscopic photographs and he proposed how motion and depth could be combined. Wheatstone was involved with all those who made the novel developments, and his own contributions followed the sequence of discovery. First instruments were devised which simulated motion from a sequence of briefly presented but slightly different pictures. Secondly, the stereoscope simulated objects in depth by presenting slightly different pictures to each eye. The slight spatial differences proved easier to capture photographically. Wheatstone suggested that sequences of stereoscopic photographs could be presented to simulate motion in depth. Later in the nineteenth century, sequences of photographs taken in rapid succession were presented in modified phenakistiscopes and zoetropes to provide more realistic representations of biological motion. However, then as now, the motion component was easier to simulate than the briefly presented stereoscopic effects.

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Table 1. Optical instruments invented or developed in the early nineteenth century.

Instrument	Inventor	Year Invented	Published account
Kaleidoscope	David Brewster	1816	1818
Thaumatrope	John Ayrton Paris	1825	1827
Kaleidophone	Charles Wheatstone	1827	1827
Counterrotating discs	Michael Faraday	1831	1831
Phantasmascope	Peter Mark Roget	1831	1834
Stereoscope	Charles Wheatstone	1832	1838
Phenakistiscope	Joseph Plateau	1832	1833
Stroboscopic disc	Simon Stampfer	1832	1833
Daedaleum	William Horner	1834	1834
Daguerreotype	Louis Daguerre	1839	1839
Calotype/Talbotype	W H Fox Talbot	1839	1839
Lens stereoscope	David Brewster	1849	1849
Binocular camera	David Brewster	1851	1851
Bioscope	Jules Duboscq	1852	1852
Fantascopic stereoscope	Antoine Claudet	1852	1852
Red/blue anaglyph	Wilhelm Rollmann	1853	1853

Figure legends

Figure 1. Upper left, *Plateau's phenakistiscope* and upper right, *Stampfer's stroboscopic disc* (both by Nicholas Wade). Lower, an illustration of viewing rotating drawings with the phenakistiscope or stroboscopic disc of the type described by Plateau and Stampfer.

Figure 2. Upper, Horner's dædaleum as illustrated in Helmholtz (1896). Lower, Horner's (1834b) illustrations of the visibility of retinal blood vessels in his right eye (left) and around the fovea (right).

Figure 3. *London circle*. The central figure is Charles Wheatstone (1802-1875), who was both the youngest and most instrumental of the London scientists involved in the experimental investigations of space and time in the early nineteenth century. The others are shown in clockwise chronological sequence from Thomas Young (1773-1829) at the top to Peter Mark Roget (1779-1869), John Ayrton Paris (1785-1856), Michael Faraday (1791-1867), Charles Babbage (1792-1871), and William Henry Fox Talbot (1800-1877).

Figure 4. Left, Purkinje's phorolyt or kinesiskop and, right, a series of photographs from 1865 of Purkinje rotating; they were arranged on a disc for observation in the kinesiskop.

Figure 5. *Reynaud's theatre* by Nicholas Wade. The praxinoscope was marketed in a box which could be constructed in the manner shown so that the observer's view was confined to the area of the reflected image.

Figure 6. Left, Muybridge's zoöpraxiscope which projected images on a rotating disc, like the one on the right (which also contains Muybridge's portrait – *Muybridge dancing* by Nicholas Wade).

Figure 7. Upper, *Chronophotographer* by Nicholas Wade. Marey's portrait appears successively more clearly as the marching matchstick man moves from left to right. The chronophotograph was derived from a model, dressed as the figure lower left, walked in front of a black background. Lower centre, the photographic rifle that could capture many images in a second. Lower right, Marey's models of birds in flight that could be observed through the slits of the dædaleum/zoetrope. (Lower images from Marey, 1895).

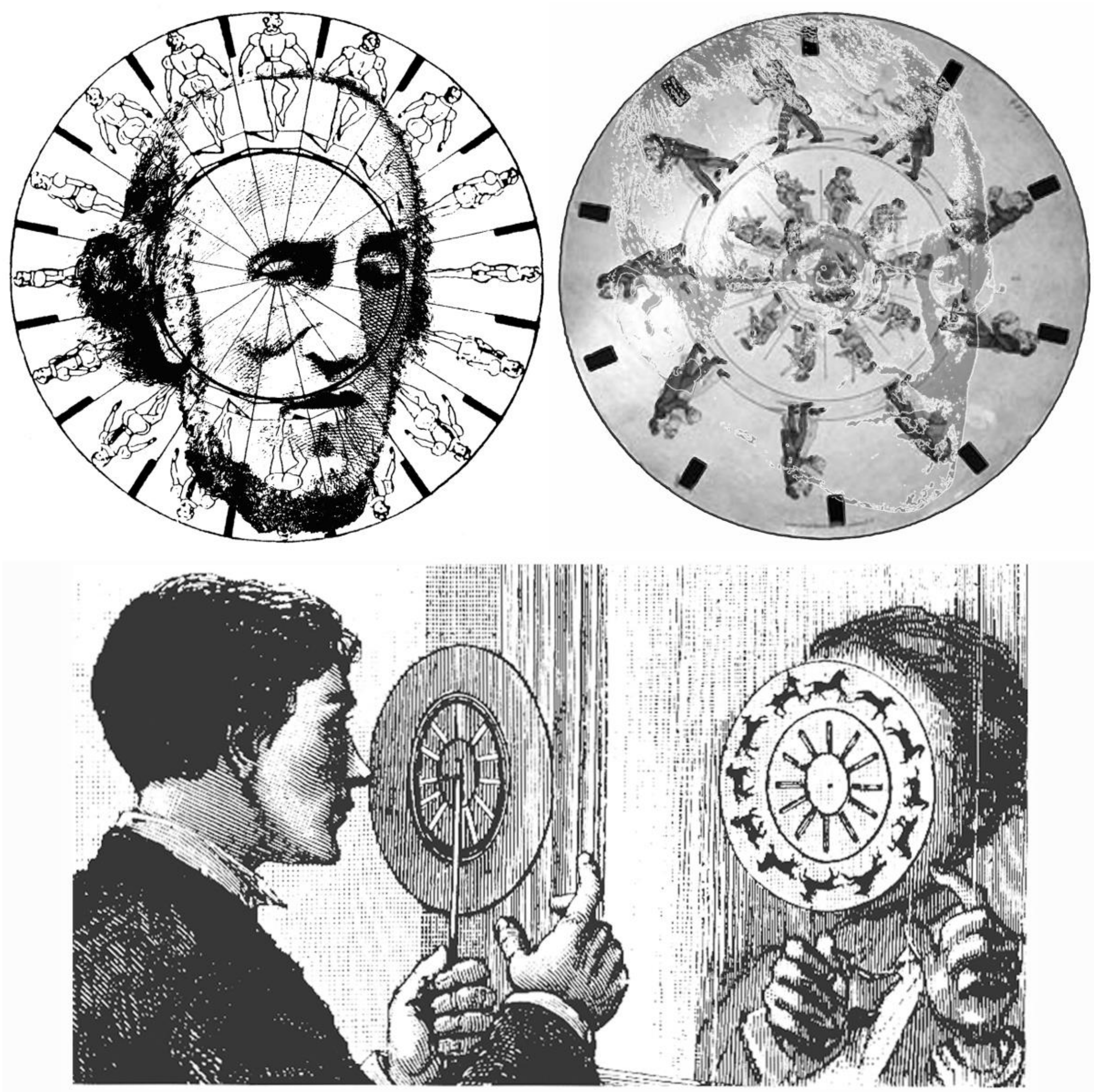
Figure 8. *Stereoscopist* by Nicholas Wade. Wheatstone is shown in his diagram of the mirror stereoscope taken from his original article (Wheatstone, 1838).

Figure 9. Upper left, *Brewster's stereoscope* by Nicholas Wade. The stereoscope was made from a single lens which was divided and turned so that the half-lenses worked as both prisms and magnifiers; the optics of the lenticular stereoscope is shown on the upper right. Lower left, George Lowdon (1825-1912) who made Brewster's first stereoscope. Lower right, Brewster's binocular camera, as illustrated in Brewster (1856).

Figure 10. Upper, a stereodaguerreotype of the Wheatstone family, taken by Antoine Claudet. Lower, a stereocalotype of Brewster, sitting beside a model of his lenticular stereoscope, probably taken by Thomas Rodger at St. Andrews.

Figure 11. Left, *Duboscq's beautiful stereoscope* by Nicholas Wade. A portrait of Duboscq is shown in text (from Brewster, 1856, p. 31) describing his lenticular stereoscope, which was presented to Queen Victoria. Right, *Claudet's clients* by Nicholas Wade. Claudet can be seen combined with photographs he took of Daguerre, Talbot, Wheatstone and Faraday (clockwise from the top left)

Figures



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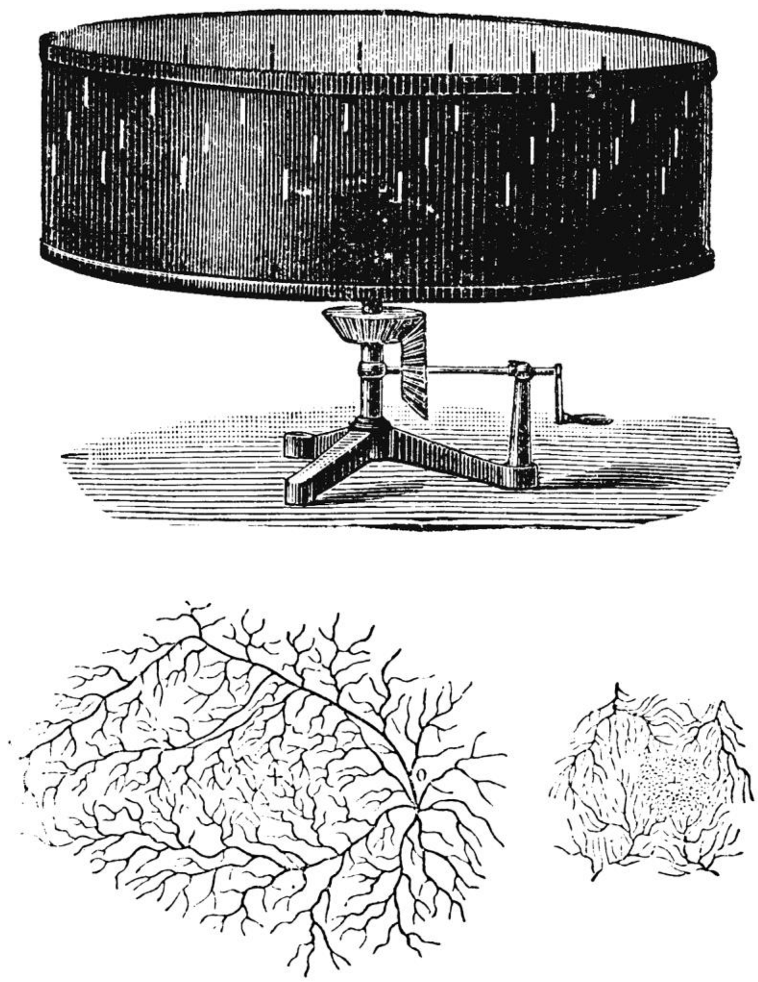


Figure 2.

Figure 3.

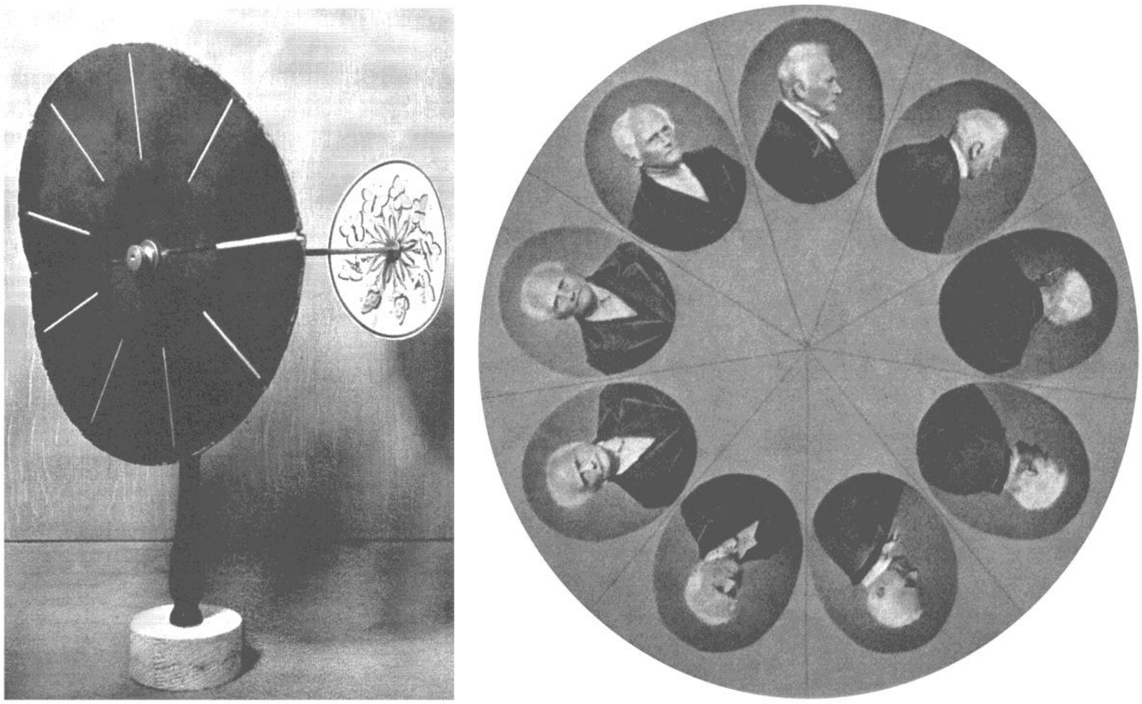
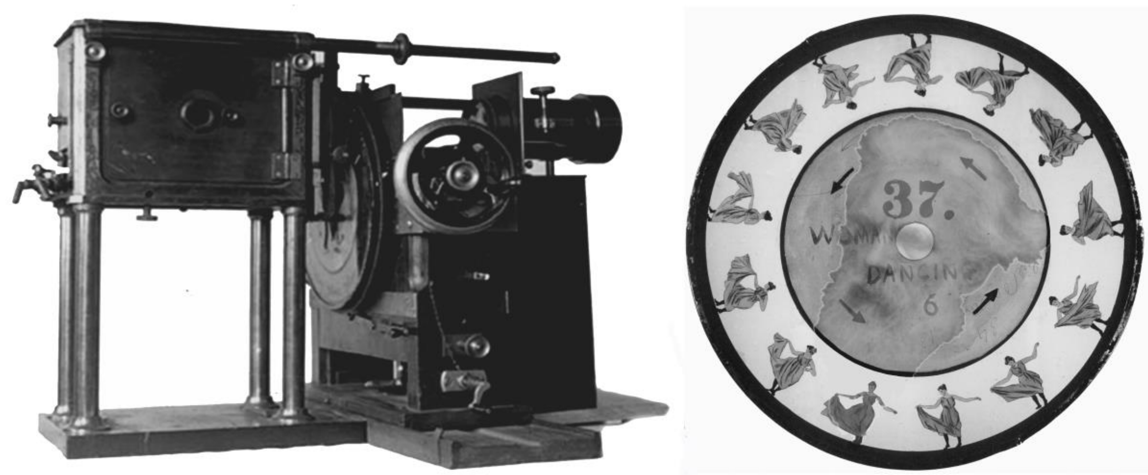


Figure 4.


LAMPASCOPE
double effet
MÉD. D'ARGENT
PARIS 1879
LE PRAXINOSCOPE
produisant l'illusion du mouvement
MÉD. DE BRONZE
MOTEUR ÉLECTRIQUE

Figure 5.



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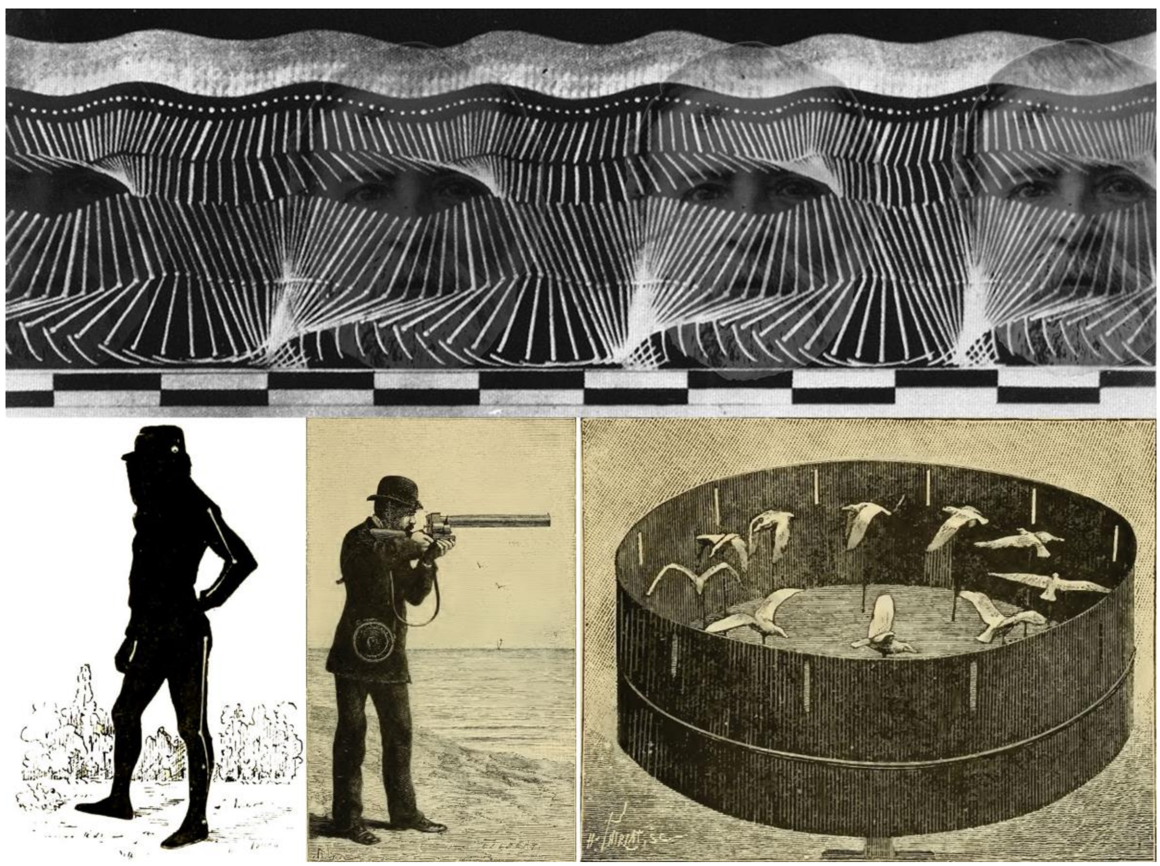

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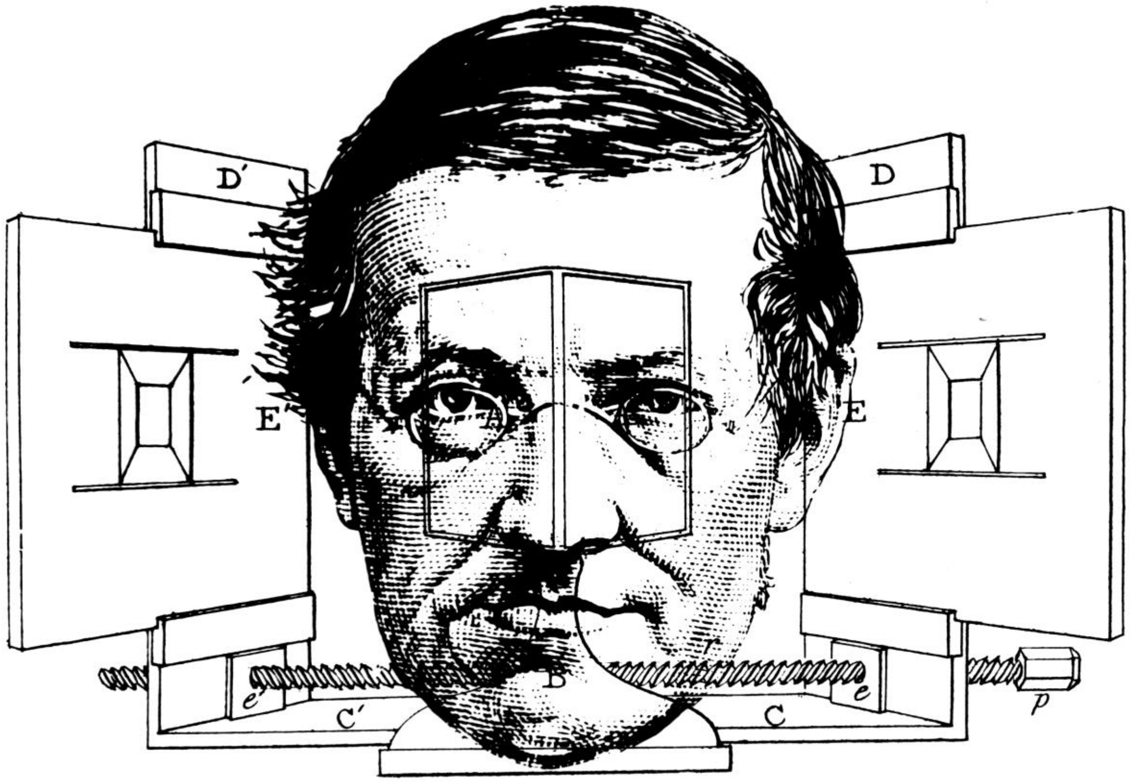

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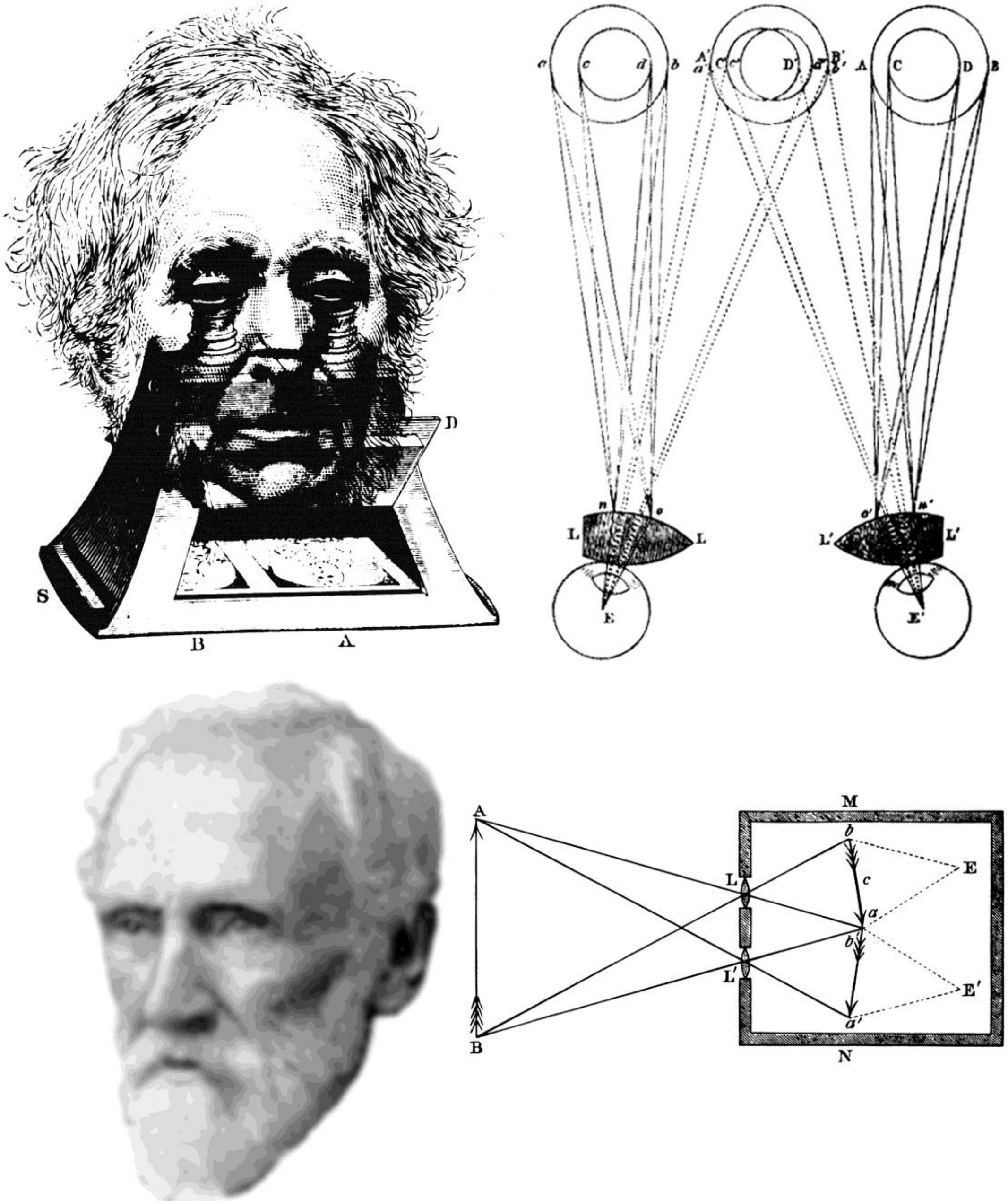
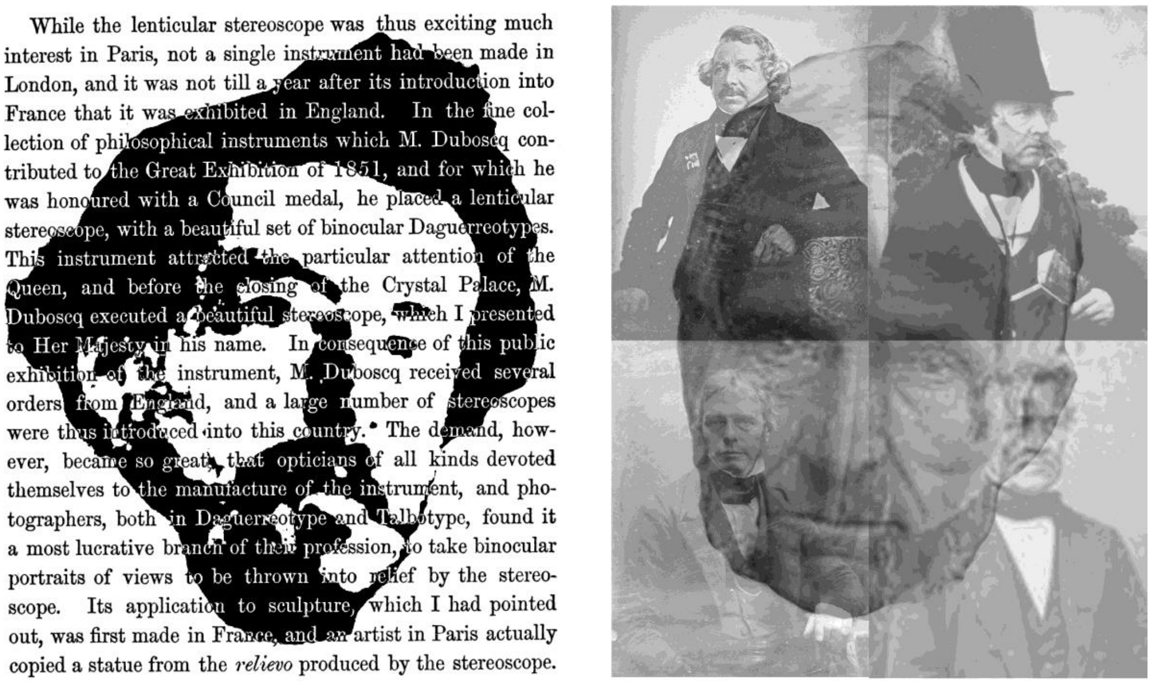


Figure 9.

Figure 10.



While the lenticular stereoscope was thus exciting much interest in Paris, not a single instrument had been made in London, and it was not till a year after its introduction into France that it was exhibited in England. In the fine collection of philosophical instruments which M. Duboscq contributed to the Great Exhibition of 1851, and for which he was honoured with a Council medal, he placed a lenticular stereoscope, with a beautiful set of binocular Daguerreotypes. This instrument attracted the particular attention of the Queen, and before the closing of the Crystal Palace, M. Duboscq executed a beautiful stereoscope, which I presented to Her Majesty in his name. In consequence of this public exhibition of the instrument, M. Duboscq received several orders from England, and a large number of stereoscopes were thus introduced into this country. The demand, however, became so great, that opticians of all kinds devoted themselves to the manufacture of the instrument, and photographers, both in Daguerreotype and Talbotype, found it a most lucrative branch of their profession, to take binocular portraits of views to be thrown into relief by the stereoscope. Its application to sculpture, which I had pointed out, was first made in France, and an artist in Paris actually copied a statue from the *relievo* produced by the stereoscope.

Figure 11.